Registration No.

24475



## Innovation Grant – Ballistically Initiated Fire Ball Generation Using M&S

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26 January 2012

U.S. Army Tank Automotive Research, Development, and Engineering Center Detroit Arsenal Warren, Michigan 48397-5000

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#### 14. ABSTRACT

Evaluated EPIC & CTH codes initially for a simple case of sphere travelling at a high velocity impacting a liquid filled cylinder for which test results are published in the literature. EPIC was eliminated as a potential software due to the excessive amount of computational time required. CTH software from Sandia is used to simulate a EFP threat hitting a Bradley fuel tank filled with water placed on a test stand. Obtained preliminary results for the liquid ejection and energy deposited into the tank and fluid by the threat. Simulation results for the failure of the tank seem to qualitatively agree very well with the SWRI test results. Shock physics codes can not predict spray characteristics such as particle size and distribution. This phenomenon of primary and secondary break-up needs further study and also influence of factors such as pressure, surface tension, viscosity and turbulence on atomization. Atomization of fuel information can be specified as input into a Computational Fluid Dynamics code for fire suppression simulation.

#### 15. SUBJECT TERMS

Simulation, CTH, CFD, fire suppression, shock physics, and SWRI

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#### TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

## **Ballistically Initiated Fire ball generation Innovation Grant**

Dr. Vamshi M. Korivi & Dr. Jian Kang GSEAA Analytics, TARDEC



#### **Outline**



- Motivation
- Approach
- Test Cases & Results
  - Liquid filled container
  - Bradley Fuel Tank with EFP
- Future Tasks & challenges
- Presentations
- References

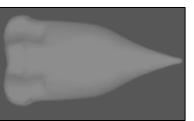


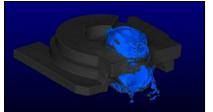
## 2011-12 Ballistically Initiated Fire Ball Generation TARDEC

People: Dr. Vamshi M. Korivi & Dr. Jian Kang, CASSI Analytics

**Objective:** Establish a simulation technique to analyze the fire ball development for end to end fire suppression digital simulation.

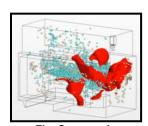
Develop a body of knowledge as to how threat, directionality, and armor type affect the ignition and initial shape of fire ball.











**Threat Formation (EFP)** 

Digital Simulation

Ballistic Penetration into a fuel cell Digital Simulation

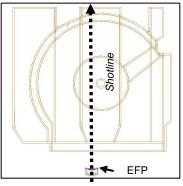
**Spray Atomization** Testing

Testing

**Fire Suppression** Digital Simulation

Output: Evaluated EPIC & CTH codes initially for a simple case of sphere travelling at a high velocity impacting a liquid filled cylinder for which test results are published in the literature. EPIC was eliminated as a potential software due to the excessive amount of computational time required for a realistic problem. CTH software from Sandia is used to simulate a EFP threat hitting a Bradley fuel tank filled with water placed on a test stand. Obtained preliminary results for the liquid ejection and energy deposited into the tank and fluid by the threat. Simulation results for the failure of the tank seem to qualitatively agree very well with the SWRI test results. Shock physics codes can not predict spray characteristics such as particle size and distribution. This phenomenon of primary and secondary break-up needs further study and also influence of factors such as pressure, surface tension, viscosity and turbulence on atomization. Atomization of fuel information can be specified as input into a CFD code for fire suppression simulation.

Relevance: A very high priority for TARDEC Survivability is the ability to develop optimized fire suppression systems for new and fielded platforms. These systems have a very high demand presently in the field and the demand for proper system design is rapidly increasing. The main current system under analysis is the Bradley, but there is a wait list of systems interested in TARDEC's capability. This research is in line with the goal of continuing to develop this new capability. It is critical to establish what types of penetrations may occur to provide the best extinguisher design.





**Simulation** 

Liquid Mass Ejected Out

**SWRI Test** TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



# Comparison of different Approaches



	Lagrangian		Eulerian	Coupled Lagrang	ian & Eulerian	
	Lagrangian Element	Lagrangian + Particle		Conformal	Non-Conformal	
Feature	Mesh moves & distorts w/ material	Fluid & failed solid are converted to particles	Mesh fixed in space	No overlapping Lagrangian & Eulerian domains	Overlapping Lagrangian & Eulerian domains	
Pros	Material interface well defined	Material interface well defined. High mesh distortion is avoided	No mesh distorsion	Well defined material interface	Simple mesh & numerically robust	
Cons	Large deformation & resulted mesh distorsion are challenging for FSI problems	CPU intensive	Material interface diffusion, extra work on solid material strength & failure computation	Need sophisticated mesh adapting algorithm. CPU intensive.	Need sophisticated interface algorithm. Material leaking might be an issue.	
Software		EPIC, Ls-Dyna SPH	СТН	Loci/Blast - Dyna coupling w/ conformal approach	Ls-Dyna ALE, Dysmas, Abaqus, Loci/Blast - Dyna coupling w/ non- conformal approach	

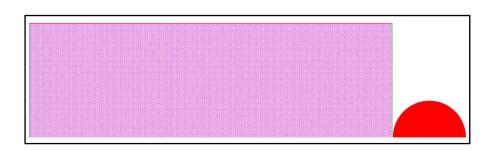


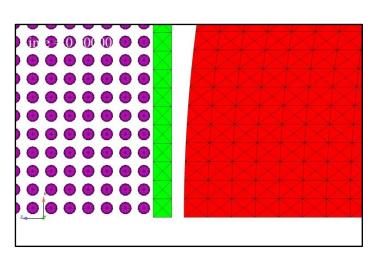
## **EPIC M&S Approach**



#### Baseline Model Highlights

- 2D axi symmetric model
- Lagrangian elements for wall and ball, and particles for liquid
- Mesh size or particle spacing: ~0.15mm
- 36 K triangle elements & 19 K nodes
- 195 K liquid particles
- Defined sliding interface among ball, wall & particles
- Converting Lagrangian elements to particles after material failure

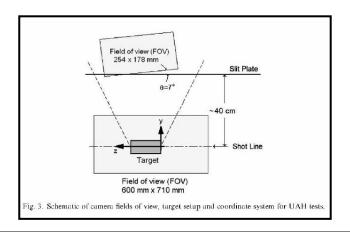


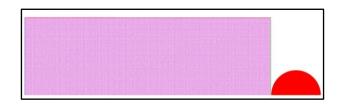


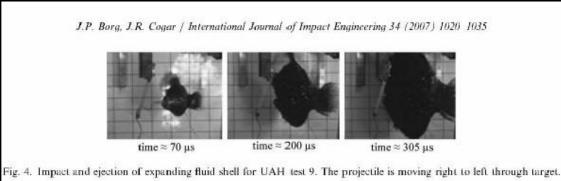


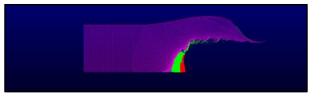
## Preliminary M&S Results & Comparison (cont.)



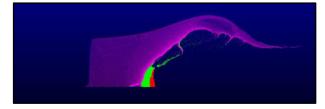








33 micro seconds



63 micro seconds

Target forms an expanding oblate spheroid

"Comparison of average radial expansion velocity from impacted liquid filled cylinders" article in Science Direct Publication



## Preliminary M&S Results & Comparison



### All cases based on UAH Test #6 (V = 2460 m/s)

#### **Status of Current Jobs in Running**

9/6/2011

Case ID	Contact Paramter SEEK	Contact Zone	# of Liquid Particles	Cores	Current Simu Time (ms)	Current WC Time (hr)	Days req. for 1.6ms Simu Time	Energy conservation	Time Step
ft3c	8	Full	100%	32	0.41	358.4	58	99.2%	1.14E-09
ft4c	0	Full	100%	1	0.26	358.3	92	99.5%	8.64E-10
ft5	8	Full	25%	32	0.73	355.3	32	99.1%	1.34E-09
ft6	8	Reduced	25%	1	0.32	165.2	34	99.1%	1.02E-09
ft6b	8	Reduced	25%	8	0.69	147.3	14	99.1%	9.77E-10

CPU time required by EPCI code deemed impractical for real 3-D problems.



#### **CTH Overview**



#### Finite-difference, Cartesian, Euler Code to model multiple materials.

- Code developed by Physicists and material not specified is considered as void.
- Van-Leer flux-splitting, second-order accurate in space.
- Interface reconstruction algorithm, SMYRA to deal with multiple materials & void in a cell.
- Ghost cell concept for boundary and interface between parallel domains.
- Turbulence can not be modeled.

#### Time integration is done explicitly and second-order accurate.

Courant number criterion and artificial viscosity for stability.

#### Novel feature:

- Transient adaptive mesh refinement/coarsening on the fly in parallel
- Refinement is isotropic in nature

#### Phenomenological models for explosives initiation.

- HVRB, forest fire etc.

#### Equation of state

Ideal gas, Mie-Gruneisen, JWL, SESAME tabular option.

#### Models for Plasticity & fracture.

- No soil model is available right now.
- Models for ceramic, composites do exist.
- Johnson-Cook, Steinberg etc.

#### No GUI for pre-processing or post-processing

- Similar to old pro-star without GUI.
- All units are CGS and temperature units are in ev. (ev is approximately = 11, 700K)

#### Simulation scales well in parallel for thousands of processors.

- Explicit, Cartesian and load-balancing using block (collection of cells) concept.

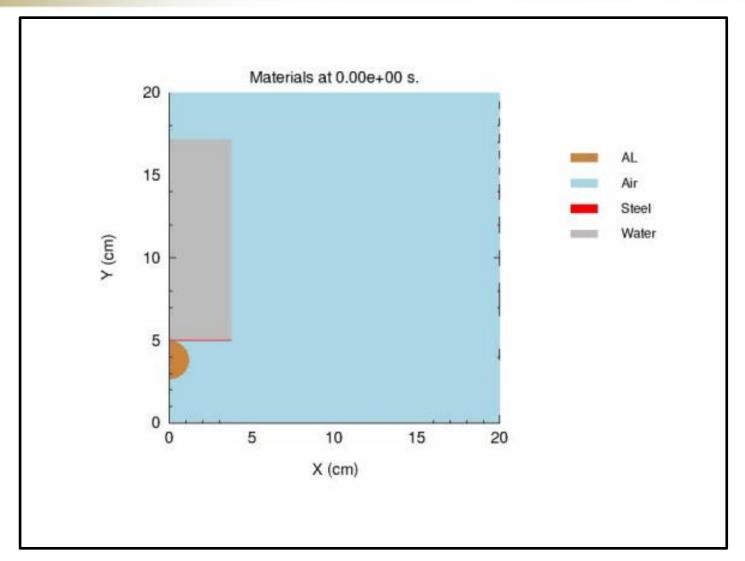
#### Main modules of the code:

DIATOM for pre, SPYHIS and SPYPLT for post-processing.



# Results from CTH (Liquid Filled Cylinder)





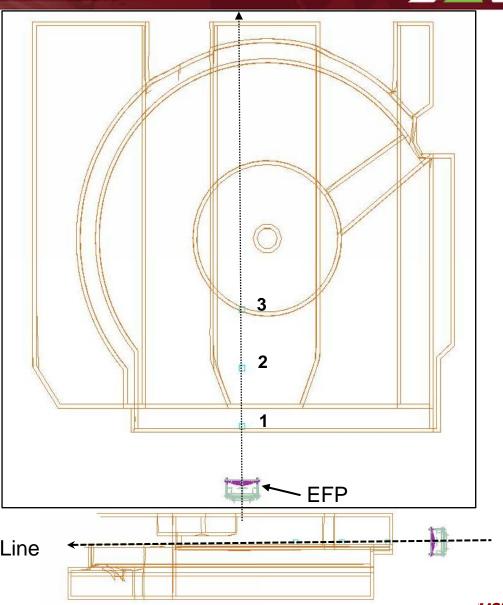


## **Bradley Fuel Tank**



#### Set Up:

- Bradley Fuel Tank: scan geometry
- EFP hitting the fuel tank on road side
- Filled with TBP fluid (similar to water)
- Tank material: similar to Nylon
- Stand Off: 8inches
- Tracer Locations:
  - Tracer near EFP Strike
  - 2. Tracer inside Fluid
  - 3. Tracer near outer wall





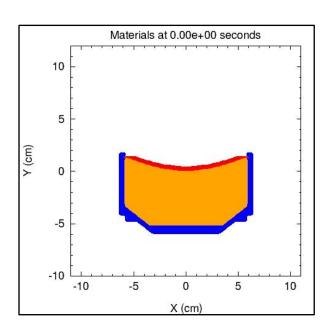
## **Generic EFP Details**

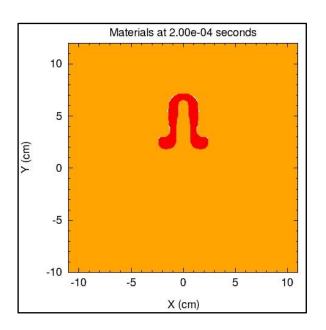


Generic EFP diameter: 127 mm

• Explosive: LX14

Steel Casing thickness: 5mm





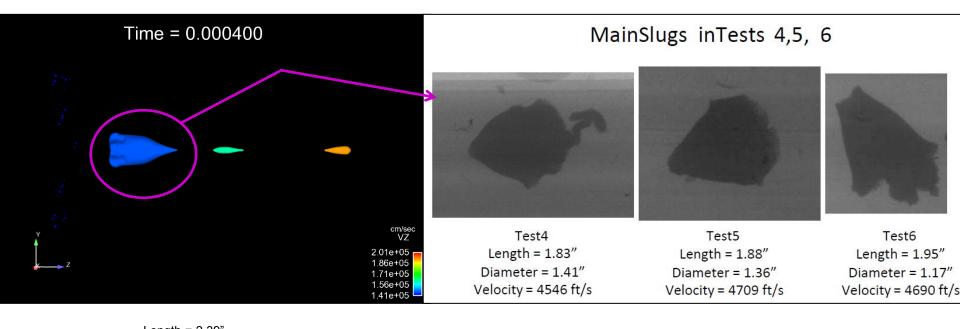


# Comparison of Simulation with SWRI testing



#### Simulation with CTH software

#### SWRI Characterization testing X-rays



Length = 2.39"
Diameter = 1.22"
Velocity of main slug = 4806 ft/sec

Velocity of lead particle = 6281 ft/sec

EFP formation is known to vary significantly in testing in terms of rotation, velocity and shape.

Capturing testing variability is a big challenge for simulation.



### **Simulation Details**

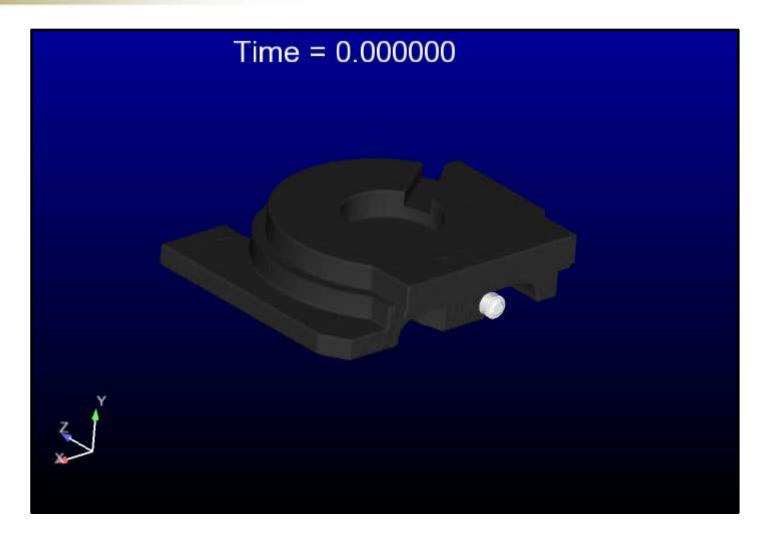


- No. of Materials: 5
- Material Strength description
  - Linear elastic and perfectly plastic description
- EOS
  - Mie Gruneisen
  - JWL for explosive
  - Phenomenological Model for EFP
    - High Explosive input for programmed burn
- Mesh Size: 13 million Cartesian cells
- Geometry Insertion: Stereo lithography format for fuel tank
- No. of CPUs: 64
- Duration of simulation: 4 ms
- CPU time: 4 days
- Post-processing Software: Ensight



## Bradley Tank Filled with liquid Animation

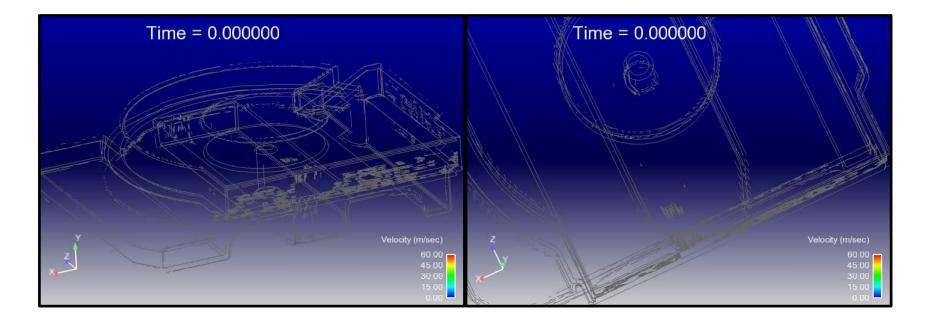






## **Shock Propagation**

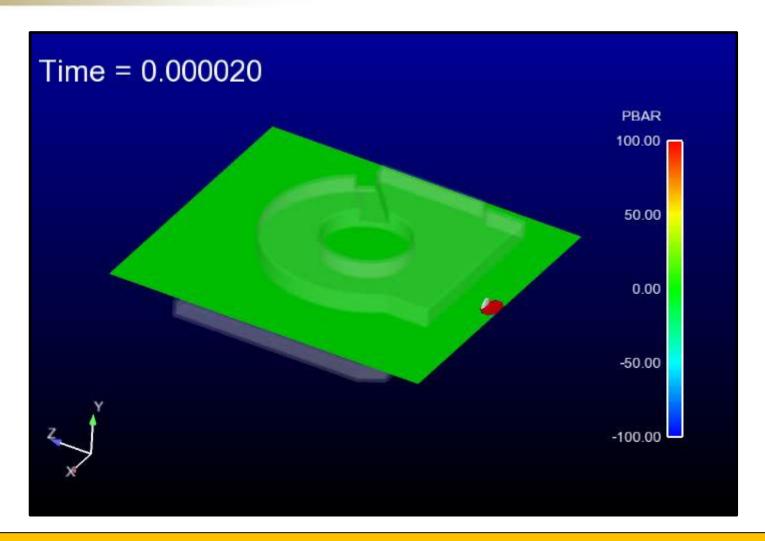






### **Pressure Distribution**



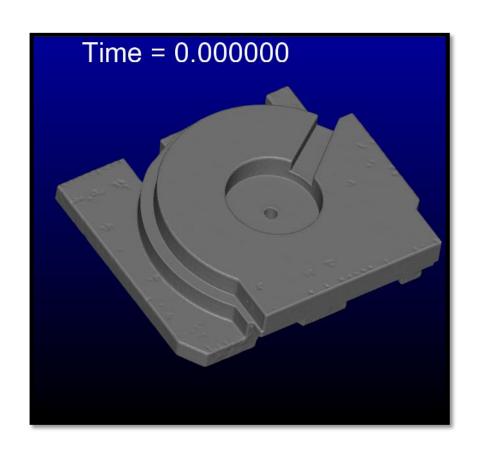


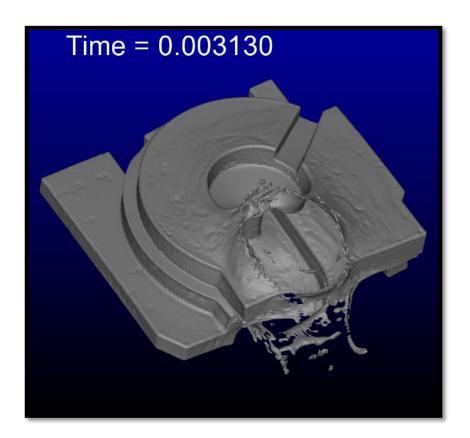
Negative pressure are observed near the walls as the structures deforms but the liquid can not follow the structure



## Fuel tank geometry comparison



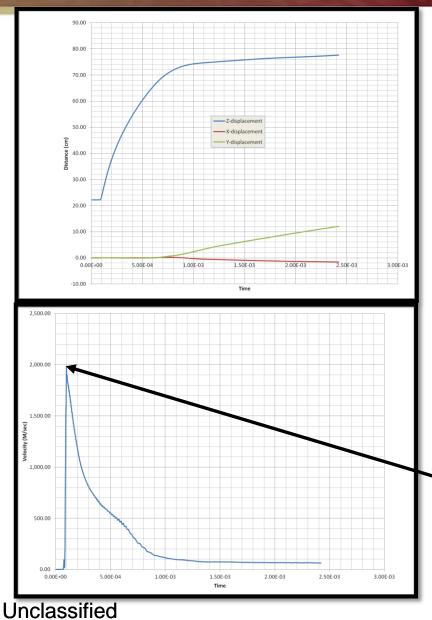


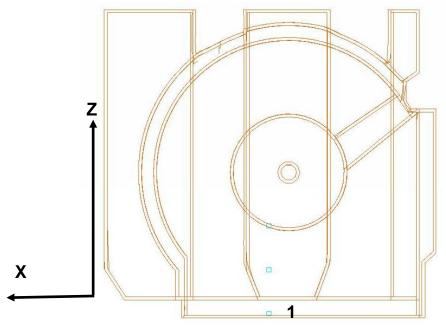




## **Velocity At Tracer 1**







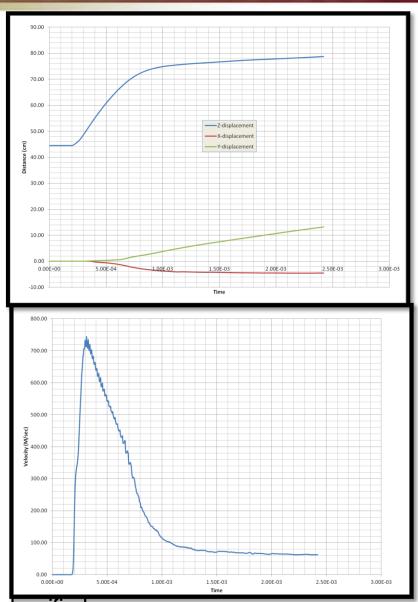
Displacement @ marker 1 is high in "Z" direction and later in "Y" direction as the tank ruptures

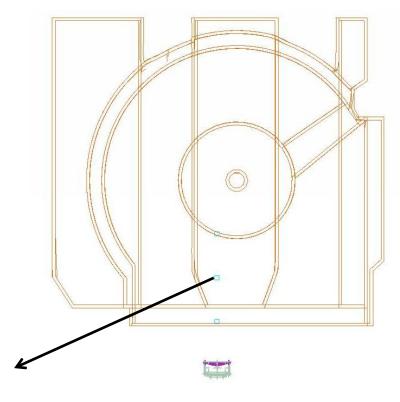
EFP hits tank with about 2 km/sec



## **Velocity At Tracer 2**







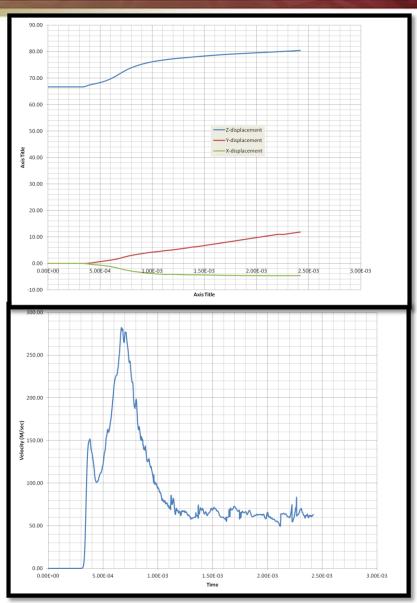
Displacement @ marker 2 is high in "Z" direction and later in "Y" direction as the tank ruptures

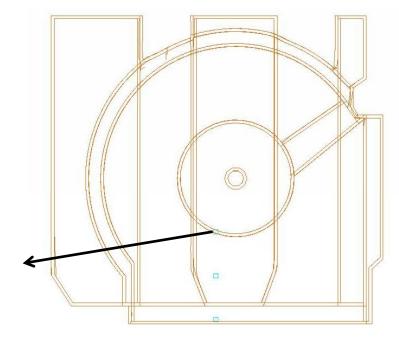
Peak velocity is reduced to 700 m/sec



## **Velocity At Tracer 3**







Displacement @ marker 3 is increasing more in "Y" direction in the rupture direction since the velocity of projectile is decreasing and strength of the tank is higher in "Z" direction to move.

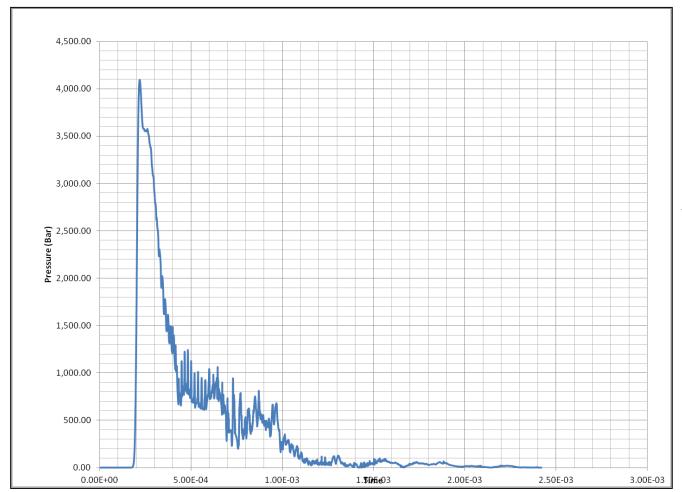
Peak velocity is reduced to 250 m/sec

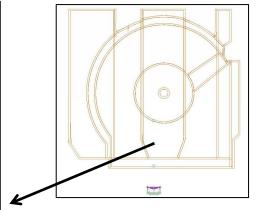
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## **Liquid Pressure**





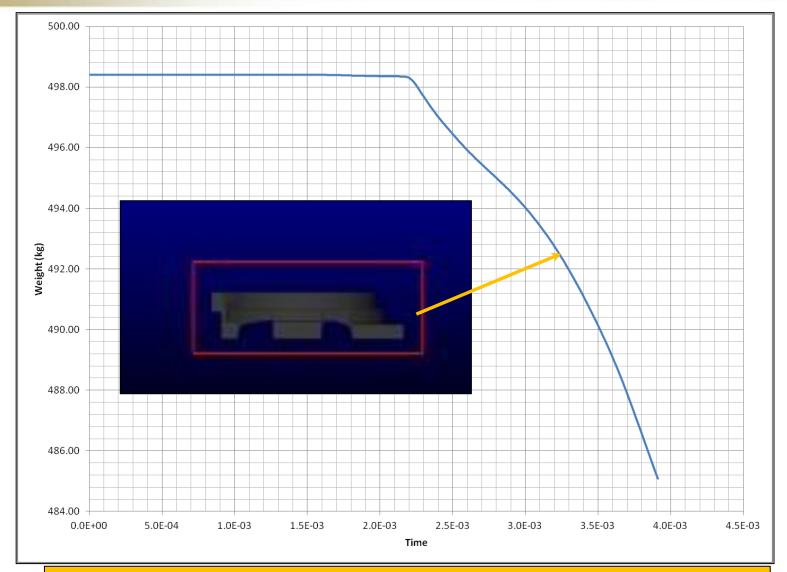


Peak pressure inside the fluid reaches 4100 bar.



## **Liquid Mass Ejected Out**



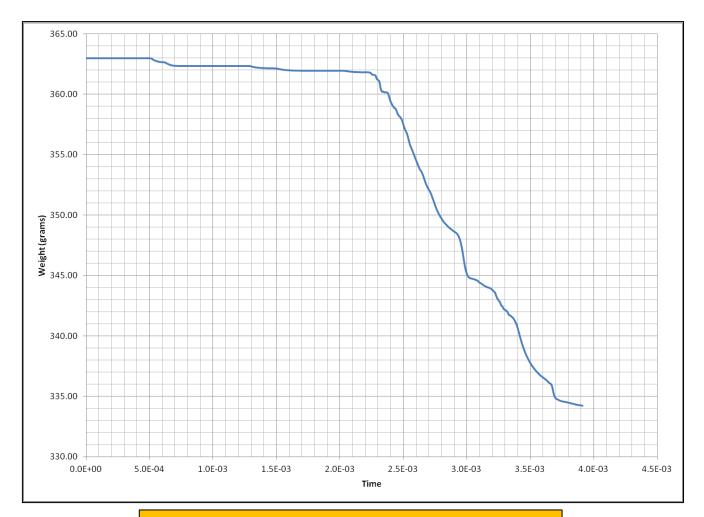


Flow rate information that is useful for fire suppression simulation



## **Projectile Copper Top**



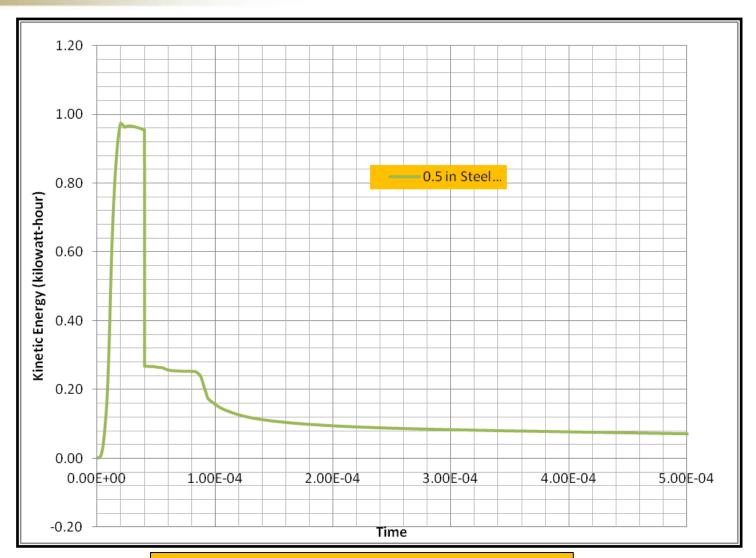


Amount of the EFP copper head that is left in the domain



## **Deposited Kinetic Energy**





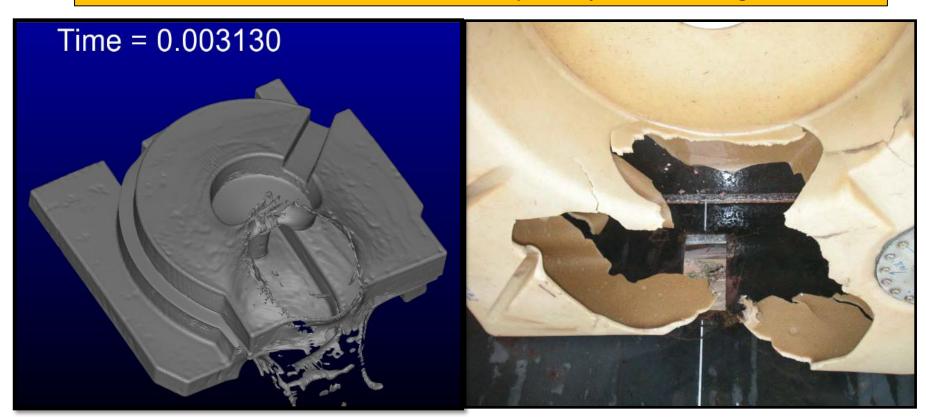
160 KJ of kinetic energy gets deposited into the water



## Ballistically initiated fire ball generation Fuel Tank



Predicted fuel tank failure seem to compare very well with testing data



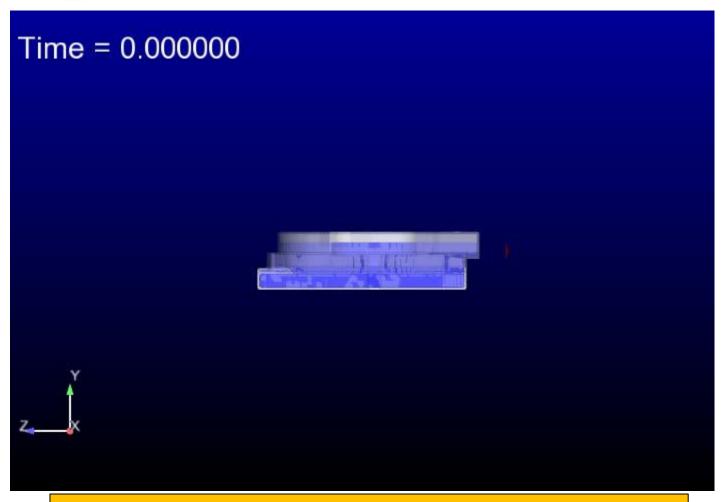
**Simulation** 

**SWRI Test** 



## **Partially Filled Tank**





Damage to the tank seems to be less compared to the tank completely filled with liquid

This is mainly attributed to compressibility of air



# Presentations/Participation workshops



- ARL fire protection workshop
- US/UK IEA1533 Survivability exchange Meeting
- JASPO/TARDEC collaboration Meeting
- Hydrodynamic workshop @ SURVIAC
- Participated in SWRI testing funded by GSS



### **Future Tasks/Challenges**



- Predict the spray characteristics such as particle size and distribution based on the Volume of fluid information (VOF) from the hydro code
- Understand the ignition phenomenon
- More experience with shock-physics software
  - Model the tank and EFP separately
  - Size of mesh resolution (0.1mm) driving computational effort
  - Run multiple simulations for grid independence
- Modeling different type of threats & varying fluid levels
- Quantitative comparison of simulation results with different types of threats
  - SWRI testing initiated by Damage Reduction Team



### References

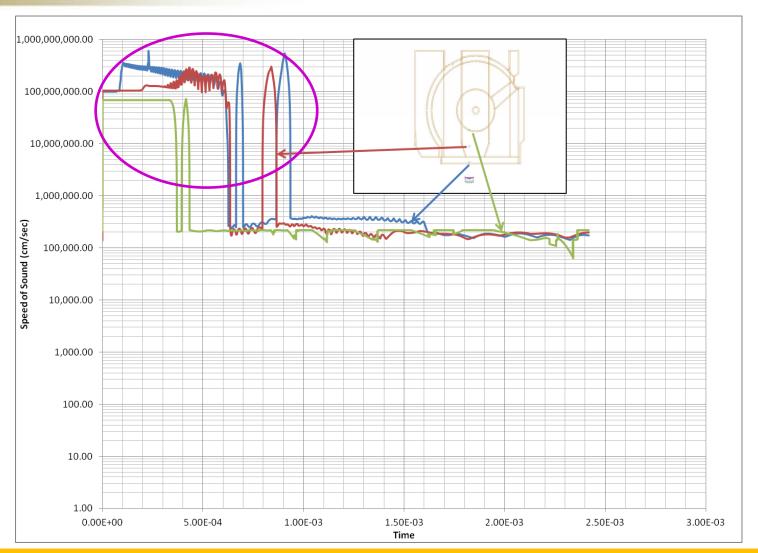


- "Comparison of average radial expansion velocity from impacted liquid filled cylinders," by John P. Borg, John R. Cogar, International Journal of Impact Engineering 34(2007) 1020-1035
- "Evolving Technology: Multi-Phase, Multi Material ALE approach and development of an automated tool for buried blast simulation" by Dr. Rahul Gupta, ARL report
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- "Simulation of Hydrodynamic Ram and Liquid Aeration", S.C. McCallum and D.D. Townsend, Presented at 5<sup>th</sup> European LS-DYNA Users Conference
- "Bradley Lower Fuel Tank Characterization tests", by Donald Grosch, SWRI Project No. 14734.16 report.
- "A review of the analyses of Hydrodynamic Ram", by Philip Fry, Technical Report AFFDL-75-102
- "Numerical Studies of Hydrodynamic Ram Experiments", by Christopher J. Freitas, Charles E. Anderson Jr., James D. Walker, T.R. Sharron and Ben H. Thacker; AFRL-VA-WP-TR-2001-3009



### **Unphysical Speed of Sound values**





Issue turned out to be CTH output error running in MPI mode vs serial mode